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Implementation of a new environmental impact assessment for municipal waste landfills as tool for planning and decision-making process

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Abstract

Among Latin American countries, Chile is the leader in terms of end-disposal of waste by landfill, with coverage of 83%. Accordingly, advances in waste management are currently being applied to minimize the environmental impact of existing sites. This has given rise to the need to undertake an environmental diagnosis of existing facilities in order to analyse the problems they present and take the necessary measures for reducing adverse effects. Taking into account the country's territorial division, the study began with an analysis of the seventeen points of deposit located in the Fifth Region of Valparaiso. Researchers used a methodology for measuring environmental impact of urban waste landfills developed by the University of Granada in collaboration with the Catholic University of Valparaiso. By applying this methodology a series of environmental indexes were obtained making it possible to quantify the impact of deposit points on the environmental elements surface water, groundwater, atmosphere, soil and human health. These indexes were as follows: Environmental-Landfill Interaction index; Environmental Risk Index; Environmental Weighting Coefficient; Environmental Value and Probability of Contamination. Analysis of results showed an absence of statistically significant differences in the environmental impact of the landfills, classified as low in all cases. Environmental elements most affected were groundwater and soil. The study also made it possible to compile a catalogue of all the points of deposit and draw up priorities for action.

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With the exception of one landfill which should be sealed, these action priorities will be aimed at improving the exploitation and design of existing facilities.

Keywords: Environmental impact; Landfill; Solid urban waste; Environmental diagnosis

Contents

1. Introduction

Management of solid urban waste in Latin America and the Caribbean is evolving in parallel with industrial expansion in the region [1]. It is estimated that by 2010 the population will have reached nearly 600 million [2]. The number of inhabitants in urban centres is increasing appreciably and now represents over 75% of the total population. Growth rates are among the highest in the world, as may be seen in metropolitan areas such as Sao Paolo, Mexico City, Buenos Aires or Rio de Janeiro, all of which have populations exceeding 10 million.

The absence of a modern and practical policy for solid waste management constitutes one of the weakest points in the system. Waste production varies from 0.2 to 1.4 kg/habitant per day. Treatment scarcely exists and waste disposal takes place in uncontrolled landfills or landfills which are controlled but present serious problems in terms of location, design and exploitation. Moreover, there exist numerous marginal groups who carry out recovery action in the landfills, with the sanitary risks that this implies [1–3].

Many studies have been published describing the environmental problems caused by points of disposal [4]. These may be summarised as follows: contribution to the greenhouse effect, resulting from methane gas emissions from landfills which account for 40% of total

methane gas production [5–7]; explosions and fire hazards, owing particularly to the presence of methane [8,9] and the generation of extensive toxic organic components such as aromatic hydrocarbons [10]; emissions of odours, dioxins and furans; depletion of ozone [11,12]; emission of volatile toxic organic pollutants [13]; production of noise, light fraction soil organic matter and dust; appearance of health-threatening birds, insects and rodents; damage to vegetation and soil [9,11], and contamination of groundwater and surface water [14–16], among other problems.

Chile is leader of Latin American countries with regard to end disposal of waste by landfill, with national coverage reaching 83% [1]. This has allowed a substantial improvement in design, construction and exploitation of landfills, as evidenced by landfill biogas recovery. A study carried out by UNEP [17] showed that Chile was the only country in Latin America and the Caribbean which undertook collection and exploitation of biogas (Santiago and Valparaiso), with three landfills equipped with biogas recovery systems. Nevertheless, the country's landfills continue to present considerable functional problems, with episodes of pollution related to design and exploitation. An example is the contamination of groundwater due to lack of control of leachates. Similarly, illicit gathering of rubbish from facilities is still practised by many people [1].

Present studies show that the current trend is towards the reduction of volume of waste in landfills. For this it is necessary to set up a programme of preliminary characterization, minimization, recovery and recycling of wastes. Since the need for landfills will continue, however, measures are also being taken to improve the design of new facilities. An example of this is the application of computer technology in the selection of new facility locations with minimal environmental threat [18]. Similarly, programmes are in progress for improving exploitation of deposit points or for carrying out the closure, sealing and after-care phase of landfills presenting irreversible environmental problems.

A preliminary step in action planning must be to determine the environmental situation of each landfill. A number of authors have worked on different methods for evaluating environmental impact in new landfills design plans: cause-effect matrix, revision lists, interconnection networks, ad-hoc methods, etc. [19–22]. However, these studies were not applicable in the present case, since we are concerned with operative facilities. Nevertheless, on the basis of these methods, other methods have been developed to carry out environmental diagnosis in running facilities, with the aim of resolving particular problems in certain provinces or groups of municipalities, as has been done in Huesca [23], the province of Granada [24] and the Valparaiso Region in Chile [25]. In most cases, the methods involved stocktaking of local natural phenomena in order to compile lists of impacts in the landfills where monitoring was undertaken, but the sphere of application was limited. Such methods made it possible to compare landfills environmentally, but not to take decisions about their control, closing, sealing, or recovering. Finally, it should be emphasised that in these studies there were practically no physical medium studies: all the assessments related to the release point, without taking into account the characteristics of their environment [26].

For these reasons, the University of Granada (Spain) in collaboration with the Catholic University of Valparaiso (Chile) has created a new methodology whose main objective is to characterise municipal waste landfills and to carry out an environmental diagnosis. In addition, the methodology is carried out at different release points in a region, providing environmental information on present and future state and allowing future action plans to be established. Accordingly, the University of Granada (Spain) in collaboration with the

Fig. 1. Study area.

Catholic University of Valparaiso (Chile) carried out an environmental diagnosis of deposit points in the Fifth Region of Valparaiso, using this methodology developed by the two universities [26]. The aim of this study was to determine the environmental impact, location suitability, design and exploitation of deposit points in the area, in order to establish measures for minimizing environmental hazards. Results of this study are described in the present article.

1.1. Description of study area

The Fifth Region of Valparaiso is situated at latitude of 32–34° (S) and a longitude of 70–72° (W), almost at the centre of the national territory. It is characterised by a temperate mediterranean-type climate. The area of study comprises six continental provinces with a surface area of 16,303.4 km^2 (Fig. 1). The ocean province of Isla de Pascua was not included.

Resources of the area were characterized as soil exploitation, infrastructures, urban centres, landfills, etc. Each of these aspects was analysed by means of an environmental inventory consisting of thirteen digitalized charts compiled by the Catholic University of Valparaiso as part of the research project 'Study of landfill location in the Fifth Region of Valparaiso' [27]. The 13 charts were as follows: study zone, populated areas and community borders; location of landfill; geology; seismic risk; geomorphologic units; gradients; surface hydrology and flooding risk; hydrogeology; precipitation; associated fauna and vegetation; protected areas; road infrastructure, uses of industrial and urban land and architectural heritage; energy and communications. The present study used these charts initially to locate the different deposit points in the area and thereafter in the application of the environmental diagnosis methodology to each point.

In total 17 operating waste landfills were identified. These were situated in the provinces of Petorca (communities of de Cabildo, Papudo, San Esteban), Los Andes (community of San Felipe), San Felipe (communities of Santa María, Putaendo and Quillota), Quillota (communities of Limache, Nogales and Valparaiso), Valparaiso (communities of Concon, Quilpue, Villa Alemana, Casablanca, Quintero, Puchuncavi and San Antonio) and San Antonio.

2. Methodology for environmental diagnosis of landfills

2.1. General aspects related to methodology application

The methodology developed by the two universities consists of an environmental study of urban waste landfills based on the characteristics of the area of the landfill and on the actual mass of waste. Environmental indexes are thus obtained to quantify the following aspects: environmental interaction between point of deposit and potentially affected environmental elements; environmental value of elements affected by landfills (surface water, groundwater, atmosphere, soil and human health); and environmental state of landfill exploitation [26].

By definition, the methodology should be applied to urban solid waste landfills. Landfill waste composition may be obtained from existing historical data, data characterizing waste in population centres or from on-site characterization. The diagnosis obtained is valid only at the time of evaluation, becoming increasingly invalid with the passage of time unless follow-up diagnoses are undertaken [26].

2.2. Methodology description

For each landfill studied, the methodology obtains an index entitled Environment–Landfill Interaction Index or Impact Index (ELI). The degree of impact on each environmental element is evaluated in order to characterize the overall environmental state of the landfill. Rate expression for the index is given in (1). Final values may be obtained between 0 and 135, with degree of environmental impact classified as maximum, high, average, low and null (Table 1).

$$\mathrm{ELI} = \sum \mathrm{ELI}_i \tag{1}$$

Table 1
ELI, ELI_i, ERI_i, EWC_i, Pbc_i, Pbc_j and eV_i classification Qualification

	Qualification				
	Null	Low	Average	High	Maximum
ELI	$ELI = 0$	$0 < ELI < 45$	$45 \leqslant ELI < 90$	$90 \leqslant ELI < 135$	$ELI = 135$
ELI_i	$ELI_i = 0$	$0 < ELI_i < 9$	$9 \leqslant ELI_i < 18$	$18 \leqslant ELI_i < 27$	$ELI_i = 27$
ERI_i	$ERI_i = 0$	$0 < ERI_i < 1$	$1 \leqslant ERI_i < 2$	$2 \leqslant ERI_i < 3$	$ERI_i = 3$
EWC_i	$EWC_i = 0$	$0 < EWC_i < 3$	$3 \leqslant EWC_i < 6$	$6 \leqslant EWC_i < 9$	$EWC_i = 9$
EV_i	$eV_i = 0$	$eV_i = 1$	$eV_i = 2$	$eV_i = 3$	
Pbc_i	$Pbc_i = 0$	$0 < Pbc_i < 0.33$	$0.33 \leqslant Pbc_i < 0.66$	$0.66 \leqslant Pbc_i < 1$	$Pbc_i = 3$
Pbc_j	$Pbc_j = 0$	$0 < Pbc_j < 0.33$	$0.33 \leqslant Pbc_j < 0.66$	$0.66 \leqslant Pbc_j < 1$	$Pbc_i = 3$

where, ELI is the Environmental–Landfill Interaction Index or Impact Index for overall environmental impact and i is the environmental elements: groundwater, surface water, atmosphere, soil and human health.

ELI_i is the Environmental–Landfill Interaction Index for environmental element i. This index assesses the extent of impact for each environmental element. Rate expression is given in (2). Final values may be obtained between 0 and 27, with degree of impact classified as maximum, high, average, low and null (Table 1).

$$ELI = \sum ELI_i \times EWC_i \tag{2}$$

where, ERI_i is the Environmental Risk Index for each environmental element i.

EWC_i is the Environmental Weighting Coefficient or Environmental Coefficient to weigh environmental element i.

2.2.1. *Environmental risk index (ERI_i)*

The objective of this index is to determine the environmental impact potential for each observed environmental element. This reflects whether or not there is any interaction between the processes in the deposit point and the characteristics of the environment. ERI_i rate expression is shown in (3). Final values are obtained between 0 and 27, with classifications of maximum, high, average, low and null (Table 1).

$$ERI_i = \sum (Pbc_i \times eV_i) \tag{3}$$

where, Pbc_i is the Probability of Contamination for element i and eV_i is the Environmental Value of environmental element i.

The probability of contamination for each environmental element will depend on state of exploitation, waste characteristics and distribution of deposit points in the area. In order to assess contamination probability, a number of variables named landfill variables are selected on the basis of their sensitivity to biochemical and physical processes which directly or indirectly affect extent of impact presented by a given environmental element. Evaluation of these variables makes it possible to assess contamination risks in the landfills by means of the Pbc_j, or the Probability of contamination for each contamination variable. This probability has the following rate expression:

$$Pbc_j = \frac{C_j W_j}{8} \tag{4}$$

where, j is variable for environmental element i. All the variables taken into account for each environmental element have a theoretical justification of their state, which is closely related to the processes of emissions taking place in a landfill and is based on the guidelines established in Council Directive 1999/31/EC [28].

C_j is the Classification of variable j. This depends on the state of the variable and provides information on the situation of the deposit point or the interaction between disposal processes, and the environmental characteristics in relation to the variable.

W_j is the Weighting of variable j. Since not all the variables affect the environment of the deposit point in the same way, the concept of weighting (W_j) is defined for each variable.

Finally, rate expression for the Probability of Contamination for each Environmental element i is given in (5).

$$\mathrm{Pbc}_i = \frac{\sum \mathrm{Pbc}_j}{N} \tag{5}$$

where N is the number of variables of each environmental element.

Pbc_j and Pbc_i obtain a final value between 0 and 1 with classifications of maximum, high, average, low, and null, depending on the results obtained from the appropriate mathematical formulation, as shown in Table 1.

eV_i is the Environmental Value of environmental element i. This concept is designed to identify and quantify the environmental assessment of each environmental element in the area of the landfill. The index is based on the relationship between environmental and/or social and political characteristics and emissions in the deposit point. The final environmental value for each environmental element will have the qualification of high, average, low, and null, depending on the results obtained from the appropriate mathematical formulation, obtaining a final value of 3, 2, 1 and 0, respectively, as shown in Table 1.

2.2.2. Environmental weighting coefficient (EWC_i)

EWC_i is the Environmental Weighting Coefficient used to weigh environmental element i. This coefficient allows for the fact that some environmental elements are environmentally heavier than others when quantifying the total or overall impact. The coefficient varies for each landfill, with quantification taking into account those indicators which relate extent of impact with spatial, temporal and legislative characteristics of the environmental element [19,29]. Assessment of environmental weighting coefficients is carried out by means of the rate expression shown in (6).

$$\mathrm{EWC}_i = \frac{I(R + D + E)}{3} \tag{6}$$

where, I is intensity, R is reversibility, D is duration, E is extension.

The hierarchy of results obtained for EWC_i by means of (6) should be contrasted with the current legislation on environmental protection. Following Gómez [19], different values were introduced for each indicator comprising the environmental weighting coefficient for each environmental element. EWC_i obtains a final value between 0 and 9 with classifications of maximum, high, average, low, and null, depending on the results obtained from the appropriate mathematical formulation, as shown in Table 1.

The fact that a certain variable or environmental element presents a null value for any of the different indexes or contamination probabilities, should not be taken to mean that the

variable or element does not participate in the ecosystem. Rather, it simply indicates that there is no interaction between processes occurring in a certain deposit point and the relevant environmental element. In such cases contamination or index probability is classified as null.

2.3. Data collection

Implementation of this methodology is based on the collection of data relating to the physical environment, state and characteristics of landfills. Data collection involved visiting the different landfills as well as studying existing information on deposit points and characteristics of their environment.

In order to facilitate this task, record cards for complete data acquisition were compiled. Two models were used: the first recorded environmental characteristics and the second obtained information on the physical condition of the deposit point. The first card included data such as geology, geomorphology, topography, surface water, groundwater, climate, soil uses, flora and fauna. The second card included waste composition, treatment, presence of special waste, leachates, presence of unauthorised persons, animals, lack of fences, exposed waste, lack of covering material and surface drainage.

2.4. Statistical analysis

Data obtained through this study were analysed by computer-assisted statistics, using SPSS for Windows 11.5.1 (Standard Version. SPSS Inc. 1989–2002).

Arithmetic mean was used to determine which environmental elements were most affected as a consequence of the landfills.

The Least Significant Differences test (LSD-Test) was used to measure the differences among the impact of deposit points and to know which are the environmental elements most affected. An analysis of variance (ANOVA) test was used to assess the homogeneity of variance with significance level of 5% ($P<0.05$). Schetfe's test was used to multiples comparisons and to get homogeneous group.

3. Results

In order to study the results obtained from application of the environmental diagnosis methodology, the Environmental–Landfill Interaction Index for each deposit point was analysed. In addition, the following indexes were analysed for each environmental element and for each landfill: Environmental–Landfill Interaction Index, Environmental Risk Index, Environmental Weighting Coefficient, Environmental Value and Probability of Contamination.

3.1. Environmental– landfill interaction index

Fig. 2 shows different ELI values for each deposit point studied. Statistics for the various indexes are given in Table 2. Mean value for ELI in the study area is 18.54, with a maximum value of 30.82 presented by Landfill 16, which shows the greatest environmental impact. A minimum value of 14.03 was presented by Landfill 6, which shows the least

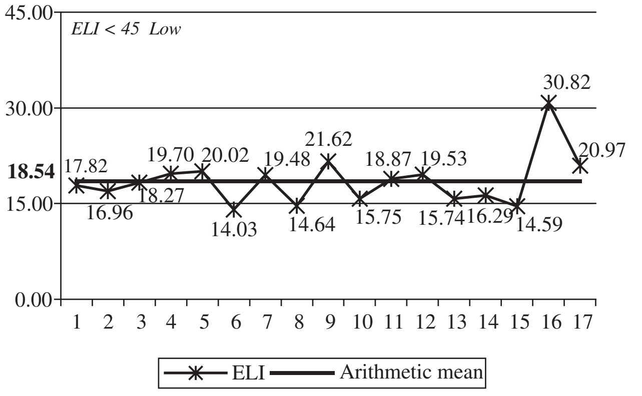

Fig. 2. Environmental–Landfill Index of each landfill.

Table 2
Statistical descriptives for the indexes

	N	Minimum	Maximum	Arithmetic Mean	Standard deviation
ELI	17	14.03	30.82	18.53	3.93
ELI_i	85	0.00	18.00	3.70	2.60
ERI_i	85	0.00	3.00	0.92	0.45
EWC_i	85	0.00	6.00	4.00	1.42
EV_i	85	0.00	3.00	2.36	0.86
Pbc_i	85	0.22	1.00	0.39	0.11

environmental impact. In all cases the ELI index obtained values under 35, falling within the classification low (Table 1).

3.2. *Environmental– landfill interaction index for each environmental element*

Fig. 3 shows ELI_i for each landfill and for each environmental element considered. Values obtained varied from 0 to 18 (Table 2), permitting classification of all cases as low or null (Table 1).

Statistical analysis of ELI_i for each environmental element shows that no statistically significant differences exist between the various deposit points ($P = 0.606$). However, statistically significant differences ($P = 0.000$) may be observed for the various environmental elements. In this case, multiple comparison data revealed two homogenous subsets. The first comprises groundwater and soil, which constitute the environmental elements with highest ELI values. The second subset comprises human health, surface water and atmosphere, which constitute the environmental elements with lowest ELI values. Table 3 shows mean values for these indexes.

3.3. *Environmental weighting coefficients*

Since the deposit points were located in the same study area, information concerning intensity, reversibility, durability and extension of effect was considered invariable for all

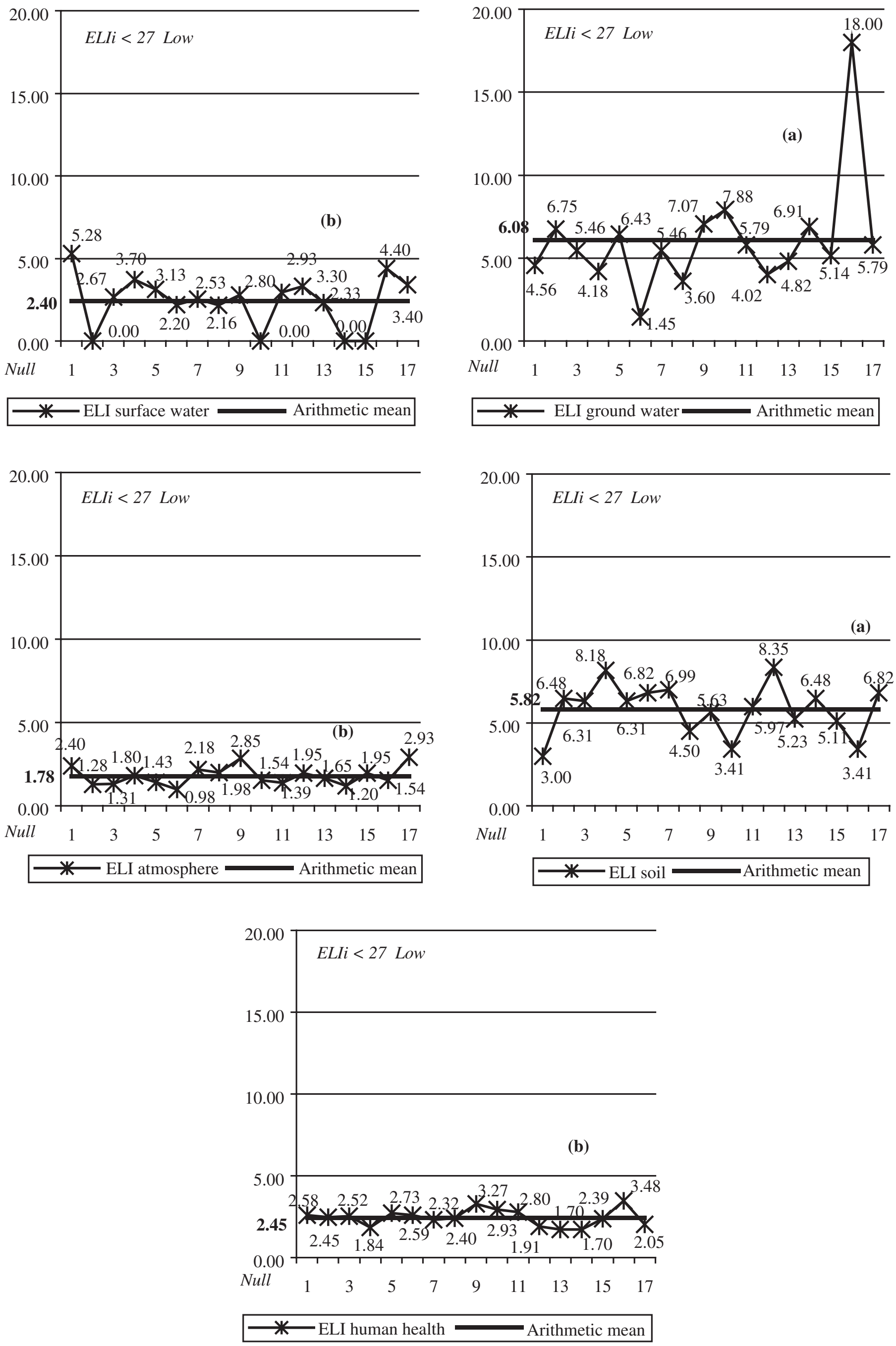

Fig. 3. Environmental–Landfill Index for each parameter of each landfill. (a) and (b): Homogeneous groups with significant differences ($P<0.05$) from other letter.

Table 3
Statistical descriptives for the indexes and for each environmental element

Environmental element	Index	Arithmetic mean	Standard error	Confidence interval 95%	
				Superior limit	Inferior limit
Surface water	ELI_i	2.40	0.46	1.49	3.32
	ERI_i	0.60	0.09	0.42	0.78
	eV_i	1.82	0.16	1.51	2.14
	Pbc_i	0.33	0.02	0.28	0.38
	Pbc_j	0.33	0.02	0.30	0.36
Ground water	ELI_i	6.08	0.46	5.16	6.99
	ERI_i	1.01	0.09	0.84	1.19
	ev_i	2.77	0.16	2.45	3.08
	Pbc_i	0.36	0.02	0.31	0.41
	Pbc_j	0.33	0.02	0.30	0.37
Atmosphere	ELI_i	1.79	0.46	0.87	2.70
	ERI_i	0.60	0.09	0.42	0.77
	eV_i	1.59	0.16	1.28	1.90
	Pbc_i	0.39	0.02	0.35	0.44
	Pbc_j	0.40	0.02	0.35	0.43
Soil	ELI_i	5.82	0.46	4.91	6.74
	ERI_i	1.17	0.09	0.99	1.34
	eV_i	2.65	0.16	2.33	2.96
	Pbc_i	0.44	0.02	0.39	0.48
	Pbc_j	0.44	0.02	0.40	0.48
Human health	ELI_i	2.45	0.46	1.54	3.36
	ERI_i	1.23	0.09	1.05	1.40
	eV_i	3.00	0.16	2.69	3.31
	Pbc_i	0.41	0.02	0.36	0.46
	Pbc_j	0.38	0.02	0.347	0.421

deposit points. In consequence, EWC_i results were the same for all seventeen deposit points, with values of 6, 5, 4, 3, and 2, respectively, for the following environmental elements: groundwater, soil, surface water, atmosphere and health.

3.4. Environmental risk index

Fig. 4 shows ERI_i results for each landfill and each environmental element. As shown in Table 2, this index varies between minimum and maximum permitted values (i.e. 0 and 3). However, in all cases ERI_i values are classified as low or null with the exception of deposit point 16 for the environmental element groundwater, which obtained a value classified as maximum (Fig. 4).

Statistical analysis of these values shows no statistically significant differences between the various landfills ($P = 0.401$), but such differences do exist between environmental elements ($P = 0.000$). Using multiple comparison of data arranged by environmental element, it was possible to distinguish between two groups. The first comprised environmental elements with highest ERI_i values, and included groundwater, soil and health. The second group comprised surface water and atmosphere, for which the index obtained lowest values. Mean values of this index for each environmental element are shown in Table 3.

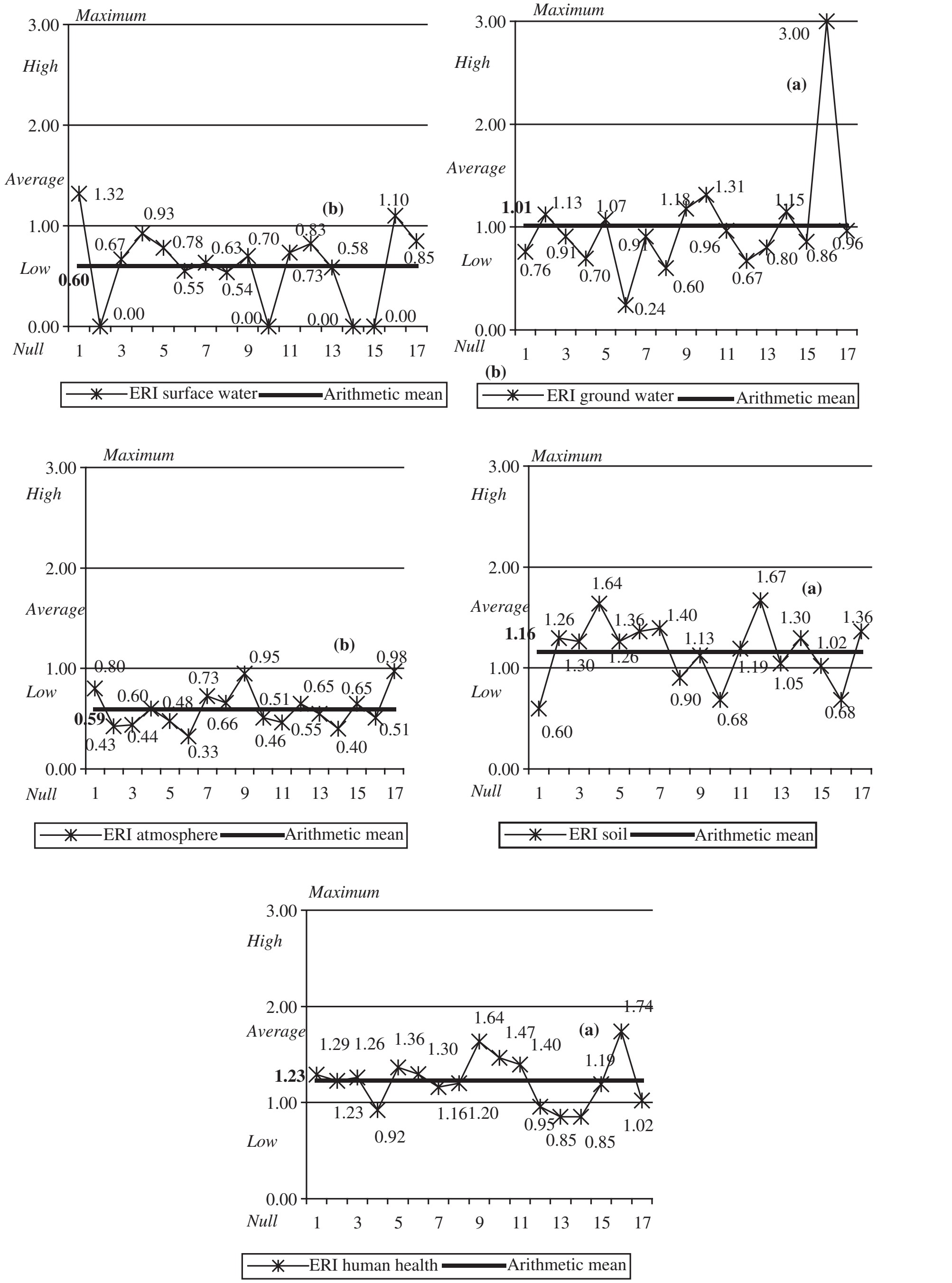

Fig. 4. Environmental Risk Index for each parameter of each landfill. (a) and (b): Homogeneous groups with significant differences ($P<0.05$) from other letter.

3.5. Environmental value

eV_i values for the different environmental elements and landfills are shown in Fig. 5. As indicated in Table 2, results vary between 0 and 3, permitting classifications of null, low, average and high (Table 1).

Statistical analysis revealed an absence of statistically significant differences between the landfills studied ($P = 0.204$). However, such differences were observed between environmental elements ($P = 0.000$). Likewise, eV_i multiple comparison distinguished two subsets for environmental elements, similar to those obtained for ERI_i. In most cases, eV_i values were higher for groundwater, soil and health, while for surface water and atmosphere eV_i values mostly corresponded to average, low or even null. Table 3 shows mean eV_i results for each environmental element.

3.6. Probability of contamination for different environmental elements

Values for this index are shown in Fig. 6, with statistical data in Table 2. In all the landfills studied, Pbc_i varied between classifications of average and low, with the exception of Landfill 16, which presented a Pbc value of maximum for environmental element groundwater.

Statistical analysis revealed an absence of statistically significant differences between landfills ($P = 0.073$) and the existence of such differences between environmental elements ($P = 0.019$). In this last case, multiple comparison of Pbc_i yielded highest values for groundwater, atmosphere and soil, while environmental elements with lowest values were health and surface water (Table 3).

Finally, analysis was undertaken of contamination probability values for the different variables grouped according to design and exploitation criteria or to landfill location (Pbc_j). As shown in Table 4, mean probability values were higher for design and exploitation.

4. Discussion

The Environmental–Landfill Interaction Index provided comprehensive evaluation of the interaction between the landfills and their environment in order to represent the environmental state of each landfill. In the present study no statistically significant differences were observed between the various landfills analysed, and the overall impact indicated by ELI was considered low in all cases.

In addition to determining overall environmental impact of the landfills, the ELI made it possible to compile a catalogue establishing a set of action priorities for the group of landfills, based on the extent of impact. The catalogue indicates that action should be taken first in Landfill 16 and last in Landfill 6.

Results also indicated which environmental elements are most affected by landfills within the study area. Groundwater and soil profiled as the elements with highest ELI_i, a finding which lends further evidence to the problems of aquifer pollution as a consequence of the absence of leachate controls [18].

By means of the ERI_i it was possible to establish the risk of impact for each environmental element, taking environmental value into account. In addition to groundwater and soil, one of the elements with highest ERI_i was human health. This

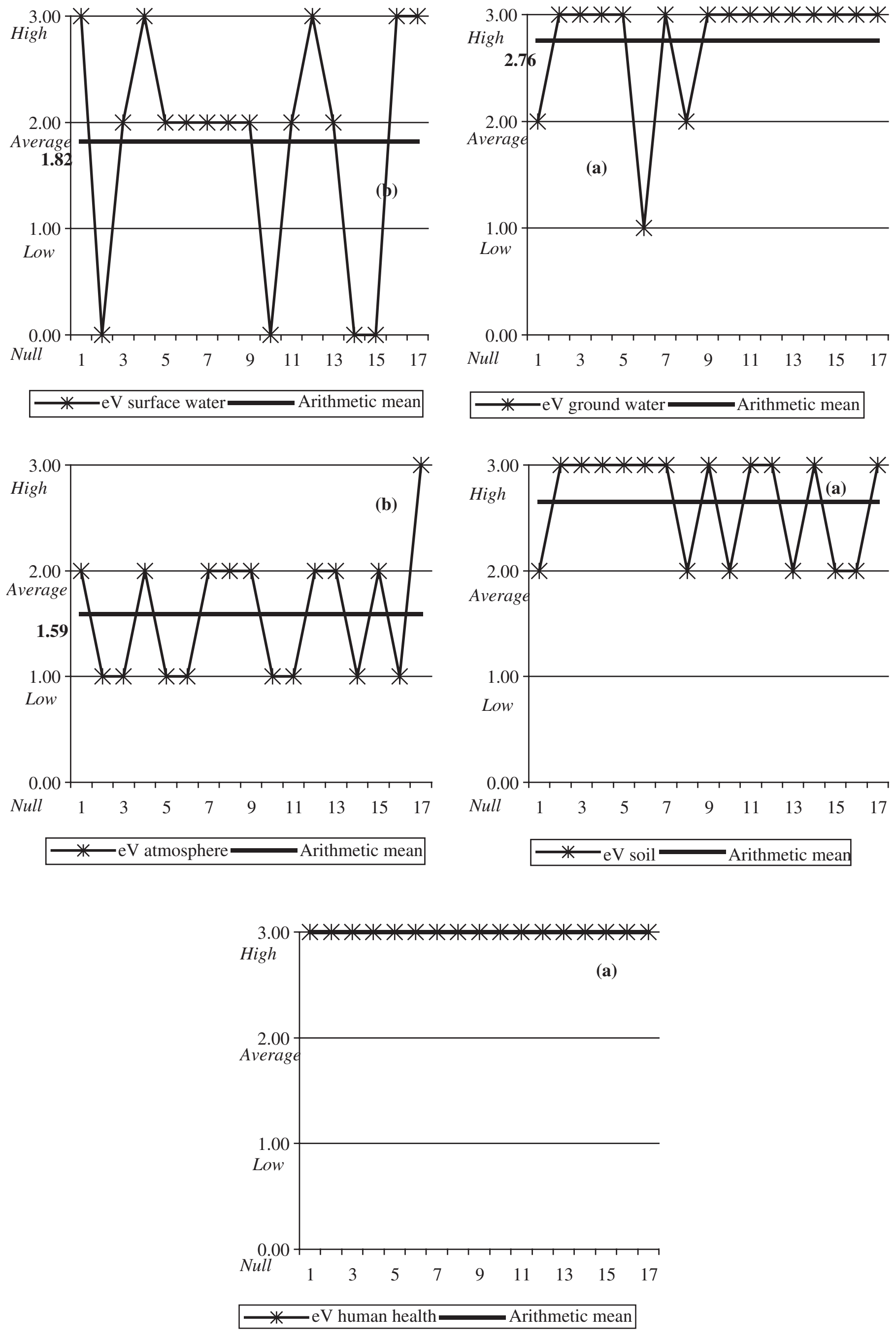

Fig. 5. Environmental Value for each parameter of each landfill. (a) and (b): Homogeneous groups with significant differences ($P<0.05$) from other letter.

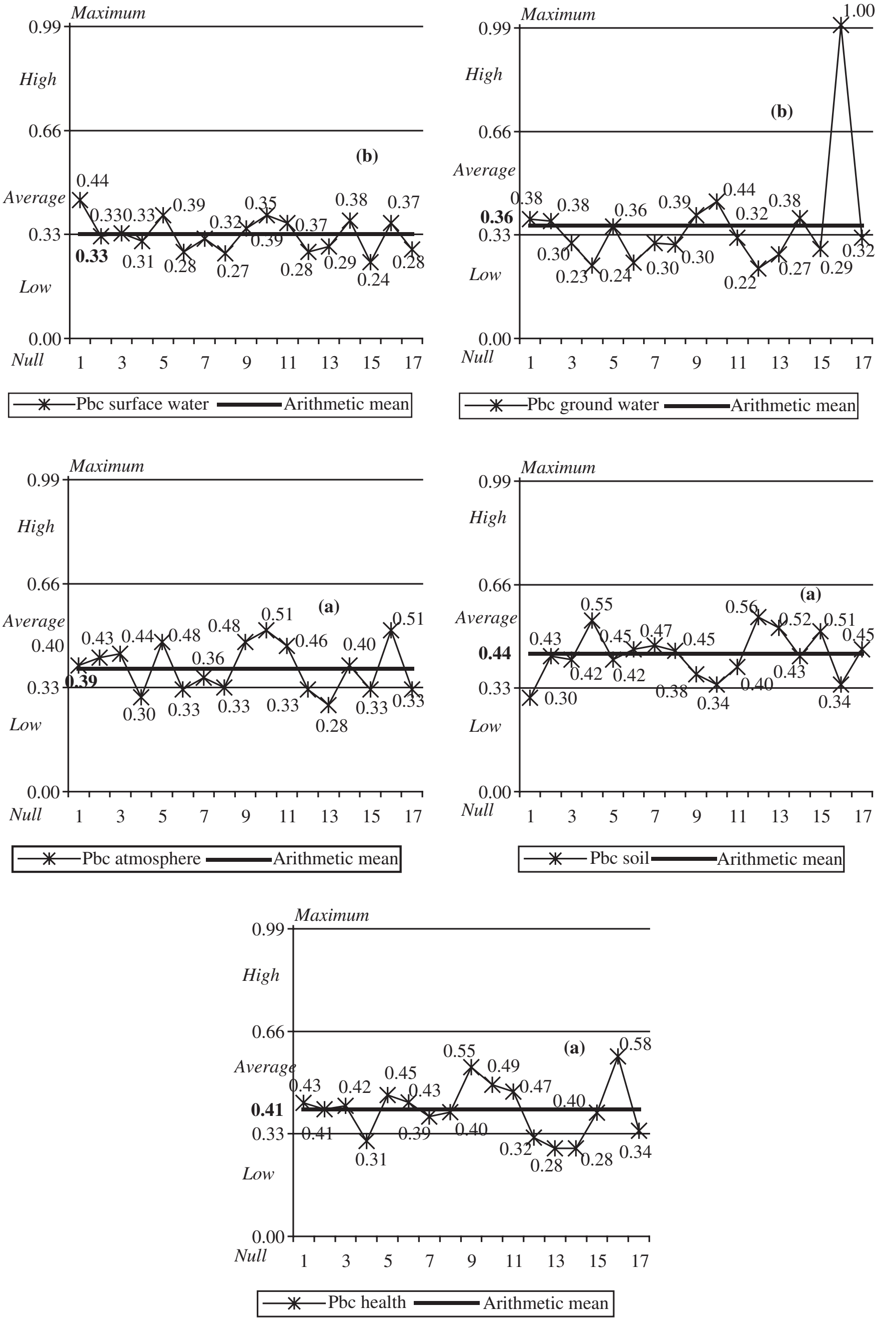

Fig. 6. Probability of Contamination for each parameter of each landfill. (a) and (b): Homogeneous groups with significant differences ($P<0.05$) from other letter.

Table 4
Statistical descriptives for contamination probabilities for the different variables (Pbc_j) grouped according to design and exploitation criteria or to landfill location

	Arithmetic mean	Standard deviation	*N*
Variables related to design and exploitation criteria	0.42	0.25	782
Variables related to landfill location	0.23	0.29	272
Total	0.37	0.27	1054

finding confirms the sanitary problems posed by landfills and provides further evidence of the inadequate conditions presented by most landfills in Latin America and the Caribbean from a sanitary point of view [1–3]. However, although the environmental element health was included in the subset with highest ERI_i values, it did not appear in the group of elements with highest values for ELI_i. This was because health obtained a value of 2 for EWC_i, which was low in comparison with values obtained by groundwater (6) and soil (5). The coefficient EWC_i related characteristics of impact generated by landfill emissions with characteristics of the environmental element viewed as a receptor element.

Pbc_i examined the relation between working state and characteristics of the landfill and dispersal characteristics of landfill emissions entering into contact with the environment. Elements with highest Pbc_i were groundwater and soil, and also atmosphere. Only in one deposit point (16) was maximum contamination probability observed. This was for the environmental element groundwater.

Results obtained for eV_i provide further evidence of the susceptibility of groundwater and soil in comparison with the other environmental elements excepting human health, which by definition of the methodology is constantly assigned maximum value [26]. In the case of surface water, Landfills 2, 10, 14 and 15 presented an environmental value classification of null, indicating an absence of surface watercourses at less than 1 km from the deposit point. Accordingly environmental risk and Environmental–Landfill Interaction Index do not apply to this element or in other words, there is no interaction between surface water and the processes occurring in these landfills.

The low ERI_i values indicate that operation of all landfills may be maintained with the exception of Landfill 16. This landfill presented an ERA_i value of high for groundwater, indicating a high risk of impact for this environmental element. Consequently it was recommended to close, seal and reintegrate the deposit point. To carry out this process, a detailed follow-up analysis of probability contamination values for all variables should be undertaken, in order to direct sealing operations. All the other deposit points may continue functioning subject to improvements in exploitation. This reflects the results of the contamination probability study, which indicated that the variables related to exploitation of waste had higher environmental values than design and location of landfills. This finding lends support to the conclusions UNEP [17] and Taulis [18].

5. Conclusions

The methodology applied to the Fifth Region of Valparaiso in Chile for environmental diagnosis of urban waste landfills provided sufficient data to determine the environmental threat posed by the landfills. Results were obtained for a series of environmental indexes

which may be used as a basic tool for the study of appropriate locations for deposit points as well as to monitor their exploitation.

Similarly, the methodology constitutes a powerful tool in the planning and prioritising of action to be taken in different deposit points in particular areas, and has led to a programme of action for future landfill investment in the area of study. This programme is to be directed first at the improvement of exploitation of facilities and secondly to improvements in design, thus reducing environmental impact. The conditioning plan for each deposit point should involve a detailed study of the contamination probability of each variable for each environmental element.

Acknowledgements

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